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UNDERWATER SHOCKWAVE FREQUENCY SPECTRUM ANALYSIS, III FREQUENCY SPECTRUM OF PRESSURE PULSES GENERATED BY ONE-POUND BLACK POWDER AND PROPELLANT CHARGES (U)

1 APRIL 1962

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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FREQUENCY SPECTRUM OF PRESSURE PULSES GENERATED BY ONE-POUND BLACK POWDER AND PROPELLANT CHARGES

by

J. P. Slifko

Approved by: E. Swift, Jr., Chief
Underwater Explosions Division

ABSTRACT: The frequency composition of the initial pressure pulse generated by underwater explosions of one-pound black powder and one-pound propellant charges encased in heavy cylindrical containers was obtained from an approximation to the Fourier transform of pressure-time records of the pulses. The spectrum level for the two explosives is about two to four db less than that for an equal weight of TNT at very low frequencies, but this difference increases rapidly with increasing frequency, and is greater for black powder. These compositions appear to have no advantage over the currently used high explosives as a sound source in explosive echo ranging.

EXPLOSIONS RESEARCH DEPARTMENT
U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

NOLTR 62-80 1 April 1962

Underwater Shock Wave Frequency Spectrum Analysis, III
Frequency Spectrum of Pressure Pulses Generated
by One-Pound Black Powder and Propellant Charges

This report is part of a continuing study on the use of underwater explosions as sound sources for locating submarines. By concentrating on the near field explosion characteristics, basic information on the suitability of various systems can be obtained without the expense of sea trials. The work was carried out under WEPTASK No. RUME-3-E-000/212-1/WF001-13-006 PA 023, Echo Ranging Explosives.

The author wishes to acknowledge the very considerable contributions of W. H. Faux who performed the computation of the data presented here.

W. D. COLEMAN
Captain, USN
Commander

C. J. ARONSON
By direction

CONTENTS

ILLUSTRATIONS

UNDERWATER SHOCK WAVE FREQUENCY SPECTRUM ANALYSIS, III FREQUENCY SPECTRUM OF PRESSURE PULSES GENERATED BY ONE-POUND BLACK POWDER AND PROPELLANT CHARGES

1. INTRODUCTION

The fact that the shock waves from high explosive charges contain large amounts of energy is an important reason why charges have been used for many years as sound sources in the sea. The almost instantaneous pressure rise and the short duration of the shock wave pressure pulse from a small high explosive charge results in a frequency spectrum which provides substantial amounts of energy at the higher frequencies. As the pressure pulse is transmitted long distances through the water, the attenuation due to absorption and scattering increases and is greater at the higher frequencies. Hence, if the energy in an explosive charge could be redistributed from the high frequency to the low frequency end of the spectrum, without decreasing the total energy, more of the energy would be transmitted to large distances. It was suggested (a)* that such a reapportionment could be obtained with propellant compositions.

Attempts by NOL to obtain pressure-time data from black powder and propellant charges encased in light metal containers failed because the pressures generated were too small for reliable measurements. Perhaps the pressure was permitted to build up only to the bursting point of the can - a pressure which is quite small. However, as the strength of the metal container was increased substantially, the amplitude of the pressure was likewise increased. The results presented herein are only for the initial pressure pulse** generated by the charges encased in thick metal containers. It may be that other types of container would further modify the amplitude and shape of the pressure pulse. Furthermore, since the data presented herein is from a single experiment, caution should be exercised in the use of the data.

2. EXPERIMENTAL ARRANGEMENTS

<u>Charges</u>. One pound of conventional (A-2)*** black powder was hand packed in a 0.5 in. standard pipe nipple and the ends

*Refers to list of references on Page 5 .
**Although the geometry did not permit bubble pulse pressure measurements of sufficient accuracy, there is evidence that the bubble pulse pressure amplitudes are of the same order of magnitude as that in the initial pressure pulse.
***Designation used by the U. S. Naval Propellant Plant, Indian Head, Maryland.

were sealed with pipe caps. In the center of one pipe cap a hole was drilled and a 3/8-in. diameter by approximately 1 3/4-in. long copper tube was soldered at its midpoint in the hole. This tube provided an entrance for an electrical cable used in the initiation of the explosive charge. The initiation was performed by means of a large electric current delivered through a nichrom wire connected across the cable leads and imbedded in the center of the top end of the explosive.

The other explosive used was the double base propellant, type ARP*, which consisted of grains 0.035-in. diameter by 0.035-in. long. The charge was initiated in a similar manner but a booster was used since at that time it was thought the propellant was somewhat more insensitive. The booster consisted of 10 grams of black powder contained in a small plastic bag, the open end of which was secured to the inside end of the copper tube. The total charge weight was one pound.

Rig and Instrumentation. The charges and four tourmaline gages were mounted inside a 17-ft. diameter ring constructed from 1-1/2-in. diameter steel bar and were set at a depth of 9 ft in about 18 ft of water. Two gages were maintained at a range of 2-1/2 ft and two at 10 ft; another gage was placed outside the ring at 40 ft from the charge. The gages used were constructed** from four 1-4-in. diameter discs of tourmaline and mounted on low-noise cable. These were then coated with a wax to a thickness less than about 1/8-in. The other end of the transmission cables terminated in compensation networks (b) and 100 megohm input impedance cathode follower circuits. The output of these was fed into Model 512 Tektronix oscilloscopes and the pressure-time records were obtained on 10-in. strips of 35mm film which were moved at right angles to the excursion of the cathode ray tube beams produced by the pressure pulses. A calibration of the time scale was provided by superimposing short duration pulses upon the pressure time signal. In addition, a step calibration voltage ("Q" step) was applied at the termination network immediately before each shot. The gage rise (response) time to a discontinuous pressure rise was found from previous tests to be about 8 to 10 microseconds on the average. The frequency response of the entire recording system was essentially flat with the 3 db points at about 1/4 cps and 100 kcps.

*Designation used by the U. S. Naval Propellant Plant, Indian Head, Maryland.
**The gages were manufactured by Crystal Research, Inc., 42 Concord Lane, Cambridge 38, Mass.

3. RESULTS

Shock Wave Records. The wave form of the pressure pulses from the black powder and propellant charges encased in thick metal containers differed appreciably from the conventional high explosive shock waves. For both explosives, the pressure increased slowly and linearly to a maximum value after which the pressure decayed exponentially at an even slower rate. For the 1-lb black powder charge, a maximum pressure (see Figure 1a) of about 16.10^6 dynes/cm^2 (232 psi) was obtained at a distance of 2-1/2 ft in about 0.63 msec. The duration of this pulse was not determined since it was cut off by the surface reflection at about 4.75 msec. For the 1-lb ARP propellant charge, a maximum pressure (see Figure 1b) of about 89.10^6 dynes/cm^2 (1290 psi) was measured at 2-1/2 ft. The time to rise to maximum pressure was only about 0.14 msec; the duration of this pulse was also cut off by the surface reflection at about 4.75 msec. Its rate of decay, however, was much faster than that for black powder. For comparison, 1-lb TNT charges at the same range show a maximum pressure (c) of about $5.30.10^8$ dynes/cm^2 (7700 psi) and a time constant of about 100 microseconds. The shape of the pressure-time records for both explosives tested was unaltered at the 10-ft and 40-ft distances, except for an earlier cut-off. Surface cut-off occurred at about 3.4 msec and 1.2 msec at the 10-ft and 40-ft distances, respectively, thus rendering these records unsuitable for integrating and spectrum analysis.

Spectrum Analysis. The frequency composition of the black powder and propellant pressure-time pulses was obtained by using the summation approximation of the Fourier transform. This transform can be expressed as follows:

$$/\phi(f)/ = \sqrt{(\phi_1(f))^2 + (\phi_2(f))^2}$$

where

$$\phi_1(f) = \int_{-\infty}^{\infty} p(t) \cos 2\pi f t \, dt$$

$$\phi_2(f) = \int_{-\infty}^{\infty} p(t) \sin 2\pi f t \, dt$$

and p (t) is the pressure-time data for the two explosives.

In this computation, a Telereadex record reading machine was used to read the pressures from the pressure-time curve at equally-spaced time increments. The time increments used were less than 20 microseconds so that spectrum amplitudes calculated for the frequencies of interest (less than about 20 kcps) were valid. The measured pressure values were punched on IBM cards for use in the IBM 704 computer. The amplitude and energy spectra were then calculated by means of a code (d) provided for the 704 computer for a total of 36 frequencies between 30 cps and 32 kcps.

In Figure 2, some of these values of the amplitude spectrum are plotted for the A-2 black powder and ARF propellant charges. The amplitude spectrum level is equal to 20 log ϕ (f) and is expressed in db re 1 dyne/cm^2/cps*. Also shown for comparison is a dashed curve for TNT. The latter curve was calculated for an exponential pulse (e) using the maximum pressure and time constant given above for 1-lb TNT charges at 2-1/2 ft distance. It is seen in Figure 2 that the spectrum level is only about 2 and 4 db less for the propellant and black powder charges respectively than it is for TNT at the lowest frequency calculated. This indicates that there is no significant difference in the impulse for the three explosives. (This difference would be still smaller had not the black powder and propellant pulses been cut off at about 4.75 msec). However, as the frequency was increased, the spectrum level for the two explosives decreased much more rapidly than it did for TNT. For example, a comparison with TNT of the energies in the frequency bands considered favorable for sound transmission, i.e., about 1 kcps to 4 kcps, shows that a reduction of 10 db to 15 db was obtained for the propellant charge and about 30 db to 55 db for the black powder charge.

The oscillations in the spectrum level for the two compositions tested may be real. The frequency at which the first minimum appears in each curve seems to be inversely proportional to the time of the maximum pressure; the proportionality factor is about 1.45.

4. CONCLUSIONS

A reduction of energy in the higher end of the spectrum (beyond that used in JULIE and similar systems) was obtained for the initial pressure pulse from 1-lb black powder and propellant charges encased in thick metal containers; the reduction was greater for the black powder. However, this energy loss did not reappear as an increase in the acoustically useful frequencies; in fact the energy was also reduced in the lower frequencies, particularly in the frequencies considered favorable for sound transmission. This reduction also was greater for black powder than for the propellant. Therefore, when compared with an equal weight of high explosive, such as TNT, these explosives appear to have no advantage in most applications as a sound source in explosives echo ranging.

---

*Since the energy spectrum level is 10 log $\frac{2[\phi(f)]^2}{\rho c}$ in db re 1 erg/cm^2/cps, it is readily obtained by subtracting 48.8 db (10 log $\frac{\rho c}{2}$) from the curves in Figure 2. ρc is the acoustic impedance of water in grams/cm^2/sec.

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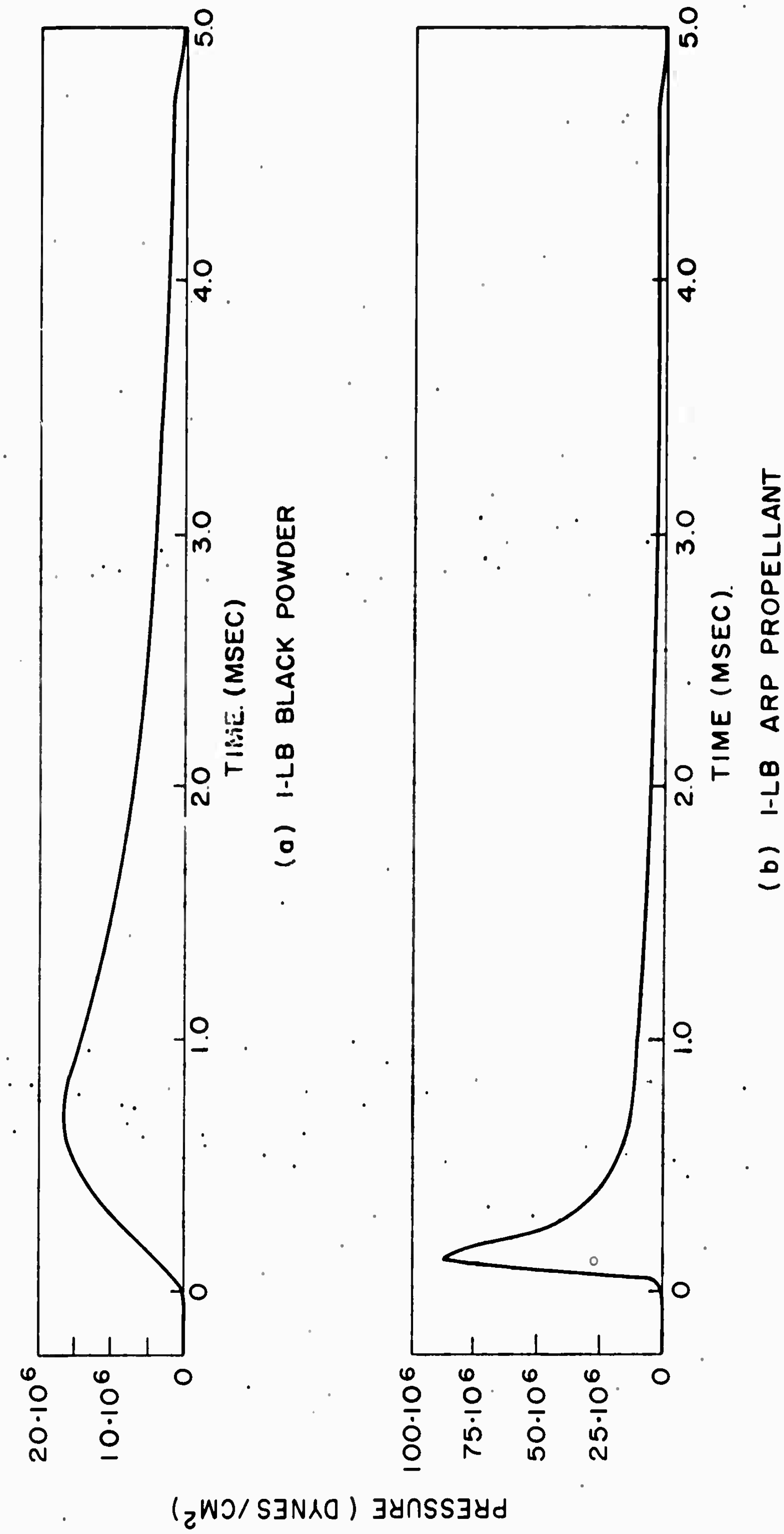

FIG. 1 INITIAL PRESSURE PULSE FROM CHARGES ENCASED IN HEAVY METAL CONTAINERS, RANGE EQUALS 2 1/2 FEET

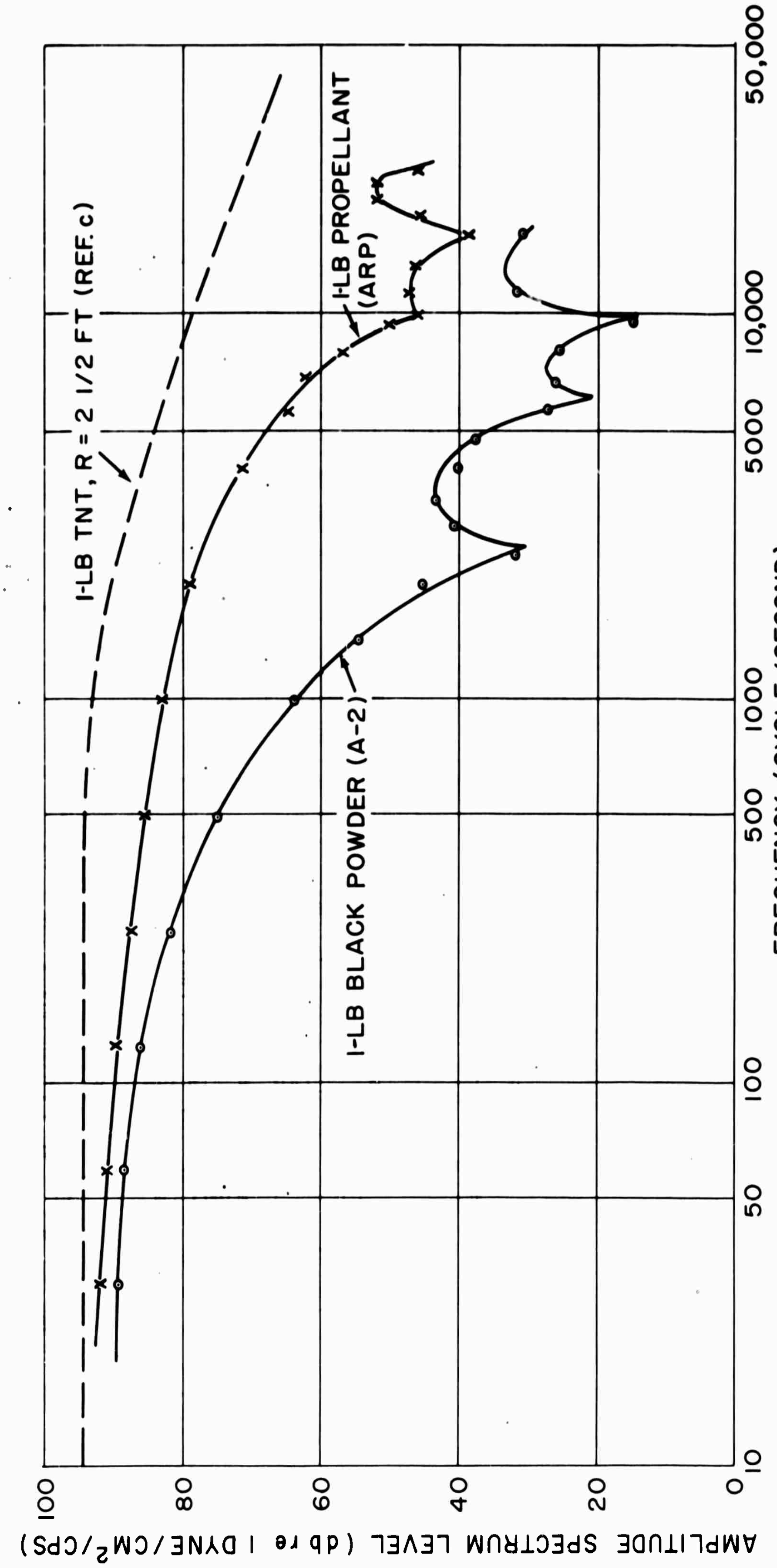

FIG. 2 AMPLITUDE SPECTRUM OF INITIAL PRESSURE PULSE FOR I-LB BLACK POWDER AND PROPELLANT CHARGES ENCASED IN HEAVY METAL CONTAINERS, RANGE EQUALS 2 1/2 FEET

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Descriptors	Codes	Descriptors	Codes	Descriptors	Codes
Underwater	UNDR	Sound	ACOU		
Shock	SHOC	Source	SOUR		
Waves	WAVE				
Frequency	FREQ				
Spectrum	SPER				
Analysis	ANAL				
Pressure	PRES				
Pulses	PULS				
Black powder	BLAP				
Propellants	FUEL				
Charges	CHAR				
Explosive echo ranging	EERA				

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 62-80)
UNDERWATER SHOCK WAVE FREQUENCY SPECTRUM ANALYSIS, III. FREQUENCY SPECTRUM OF PRESSURE PULSES GENERATED BY ONE-POUND BLACK POWDER AND PROPELLANT CHARGES(U), by J.P. Slifko. 1 April 1962. 7p. charts. WepTask RUME 3-E-000/212-1/WF001-13-006 PA 023. CONFIDENTIAL

The frequency composition of the initial pressure pulse from underwater explosions of one-pound black powder and propellant charges encased in heavy cylindrical containers was obtained from pressure-time records providing spectrum levels of only two to four db less than for same weight of TNT at very low frequencies. This deviation from the TNT level, however, increased rapidly with increasing frequency being greater for black powder.

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